Nano, Tough and Super Slick

A nanoscale coating of an aluminum-magnesium-boride helps reduce friction and boosts industrial energy efficiency

BY KERRY GIBSON

FRICTION IS THE BANE OF ANY MACHINE. When moving parts are subject to friction, it takes more energy to move them, the machine doesn't operate as efficiently, and the parts have a tendency to wear out over time.

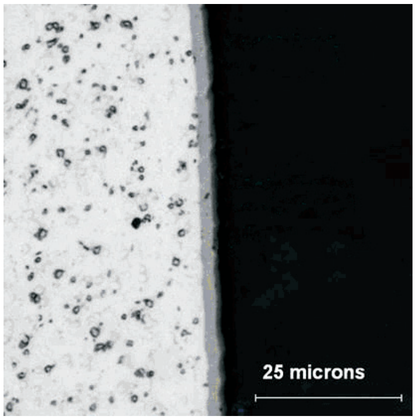
But if you could manufacture parts that had tough, "slippery" surfaces, there'd be less friction, requiring less input energy and the parts would last longer. Researchers at the Ames Laboratory are collaborating with other research labs, universities and industrial partners to develop just such a coating.

"If you consider a pump, like a water pump or a hydraulic pump, it has a turbine that moves the fluid," says Bruce Cook, an Ames Laboratory scientist and co-principal investigator on the four-year, $3 million project. "When the rotor spins, there's friction generated at the contacting surface between the vanes and the housing, or stator. This friction translates into additional torque needed to operate the pump, particularly at start-up. In addition, the friction results in a degradation of the surfaces, which reduces efficiency and the life of the pump. In other words, it takes extra energy to get the pump started, and you can't run it at its optimum (higher speed) efficiency because it would wear out more quickly."

Applying a coating to the blades that would reduce friction and increase wear resistance could have a significant effect in boosting the efficiency of pumps, which are used in all kinds of industrial and commercial applications. According to Cook, government calculations show that a modest increase in pump efficiency resulting from use of these nanocoatings could reduce U.S. industrial energy usage by 31 trillion BTUs annually by 2030, or a savings of $179 million a year.

The coating Cook is investigating is a boron-aluminum-magnesium ceramic alloy he discovered with fellow Ames Laboratory researcher and Iowa State University professor of materials science and engineering Alan Russell about eight years ago. Nicknamed BAM, the material exhibited exceptional hardness and an even lower coefficient of friction than Teflon®. The research has expanded to include titanium-diboride alloys as well.

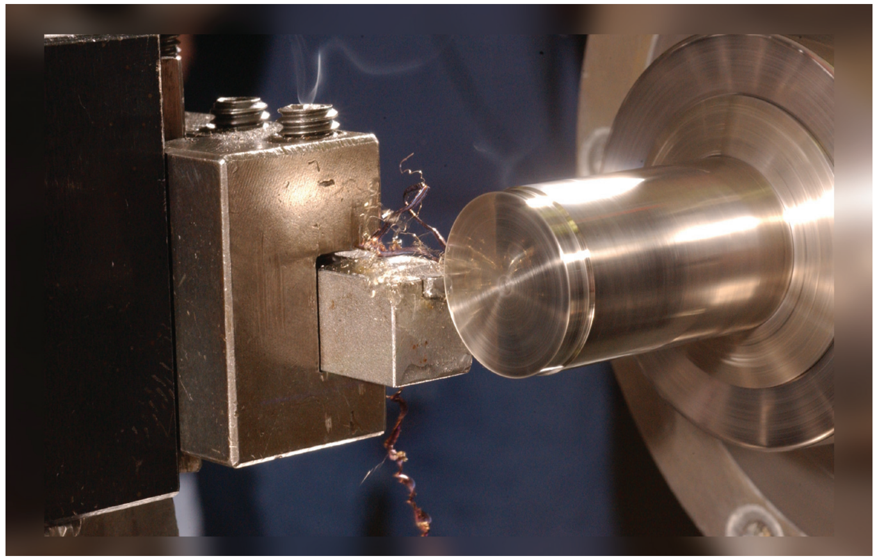
In many applications it is far more cost effective to apply the wear-resistant materials as a coating than to manufacture an entire part out of the ceramic. Fortunately, the BAM material is amenable to application as a hard, wear-resistant coating. Working with ISU materials scientist Alan Constant, the team is using a technique called pulsed laser deposition to deposit a thin layer of the alloy on hydraulic pump vanes and tungsten carbide cutting tools. Cook is working with Eaton Corporation, a leading manufacturer of fluid power equipment, using another, more commercial-scale technique known as magnetron sputtering to lay down a wear-resistant coating.



A photograph of an $AlMgB_{14}$ coating on a steel substrate. The coating is the thin, darker strip running along the edge of the steel. (The blemishes on the steel are carbide inclusions) The coating has a thickness of approximately 2 to 3 microns.

(Opposite) This image shows coating of a substrate (left) with $AlMgB_{14}$ by pulsed laser deposition. The bright plume in the center of the photograph is an $AlMgB_{14}$ plasma. The solid target is just to the right of the plume.

(Right) In an early test of BAM's capabilities, a sharpened wafer of the material is used as machine tooling to make an heavy lathe cut in hardened stainless steel.



Pumps aren't the only applications for the boride nanocoatings. The group is also working with Greenleaf Corporation, a leading industrial cutting tool maker, to put a longer lasting coating on cutting tools. If a tool cuts with reduced friction, less applied force is needed, which directly translates to a reduction in the energy required for the machining operation.

To test the coatings, the project team includes Peter J. Blau and Jun Qu at one of the nation's leading friction and wear research facilities at the U.S. Department of Energy's Oak Ridge National Laboratory, or ORNL, in Tennessee. Initial tests show a decrease in friction relative to an uncoated surface of at least an order of magnitude with the $AlMgB_{14}$-based coating. In preliminary tests, the coating also appears to outperform other coatings, such as diamond-like carbon and TiB_2.

In a separate, but somewhat related project, Cook is working with researchers from ORNL, Missouri University of Science and Technology, the University of Alberta, and private companies to develop coatings in high-pressure water jet cutting tools and severe service valves where parts are subject to abrasives and other extreme conditions. The water jets use a slurry containing abrasive grit that's forced through nozzles at 60,000 to 87,000 pounds per square inch and can make intricate cuts in almost any material without the risk of heat warpage. Unfortunately the abrasive also wears out the nozzles and the hope is that a coating of BAM can extend nozzle life.

"This is a great example of developing advanced materials with a direct correlation to saving energy," Cook says. "Though the original discovery wasn't by design, we've done a great deal of basic research in trying to figure out the molecular structure of these materials, what gives them these properties and how we can use this information to develop other, similar materials."

According to Russell, BAM isn't like most superhard materials, such as diamond, that have a simple, regular and symmetrical crystalline structure. Instead, BAM's structure is complex, unsymmetrical, and its lattice contains gaps. As for its slipperiness, Russell speculates that boron oxidation takes place on the surface and these tiny amounts of boron oxide attract water molecules from the air, to make the coating slippery.

"It's almost as if it's a self-lubricating surface," he says. "It's inherently slippery so you don't need to add oil or other lubricants."

While Cook and Russell continue their research, efforts are also underway to bring the material to the market commercially. BAM is licensed to Newtech Ceramics, an Iowa based startup company located in Des Moines. The ISU Research Foundation provided nearly $60,000 in funding for development of material samples for marketing as part of the startup effort.

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